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SOME ASPECTS OF SOVIET TRENCHING MACHINES. (U)

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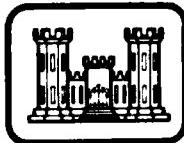
Malcolm Mellor

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By



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expected to be impressive. /

Preface

This report was prepared by Dr. Malcolm Mellor, Physical Scientist, of the Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this research was provided by DA Project 4A762730AT42, Design, Construction and Operations Technology for Cold Regions, Task A, Cold Regions Military Operations, Work Unit 002, Excavation in Frozen Ground.

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## SOME CHARACTERISTICS OF SOVIET TRENCHING MACHINES

by

Malcolm Mellor

### Introduction

The Russian technical literature contains descriptions of a wide variety of trenching machines, many of them developed or adapted for operation in frozen ground. Of particular interest are the disc saw and chain saw machines designed specifically for cutting frozen soil.

In North America, only a very few machines have been developed specifically for cutting or trenching in frozen soils, and none are really satisfactory for work in frozen gravel or frozen till because of tool breakage and rapid wear. As far as is known, there are no comparable machines produced in Europe or Japan.

In the Soviet Union, the literature indicates that many different machines have been developed for cutting trenches and slots in frozen soils. The impression conveyed is that these machines are used routinely, and that they perform satisfactorily.

In 1978 a technical exchange agreement between the USSR and the USA provided for a study of the design and performance of Soviet excavating machines, with particular reference to machines capable of work in frozen ground. The original intention was to visit design institutes, factories and construction sites so as to obtain complete information on design, construction, performance, and operating problems for selected types of machines. However, this plan did not work out, and it was only possible to obtain general design data from books and reports, mainly in the State Public Library of Scientific and Technical Literature in Novosibirsk.

In this report, certain design characteristics are compared for Soviet machines and for similar machines built in North America and Europe. The technical background to the subject is given in a series of CRREL reports by this author under the general title Mechanics of Cutting and Boring\*.

### Transverse Rotation Machines

The term "transverse rotation" is used here to describe machines in which the cutting unit is a wheel or disc that rotates about an axis perpendicular to the travel direction of the machine. The machines in question are primarily bucket-wheel soil trenchers and large disc saws intended for use in frozen soils. As a matter of interest, an attempt was also made to collect some data for dredge cutterheads.

\* CRREL Special Report 226, CRREL Reports 76-16, 76-17, 77-7, 77-19, and 78-11.

In Figure 1a, the maximum rotary speed of the wheel, drum or disc is plotted against the rotor diameter, using logarithmic scales for convenience. The straight lines drawn across the plot represent inverse proportionality between rotary speed and diameter, and thus give a range of values for the linear tool speed at the perimeter of the rotor. For most of the machines represented, tool speeds are in the range 1 to 5 m/s (200 to 1000 ft/min). There appears to be a trend to higher tool speeds on the smaller rotors.

Figure 1b gives corresponding data for various types of transverse-rotation rock cutting machines built in Europe and North America. Mining and tunneling machines that operate by transverse rotation are included in this plot. The range of tools speeds is quite similar to that found for the Soviet machines.

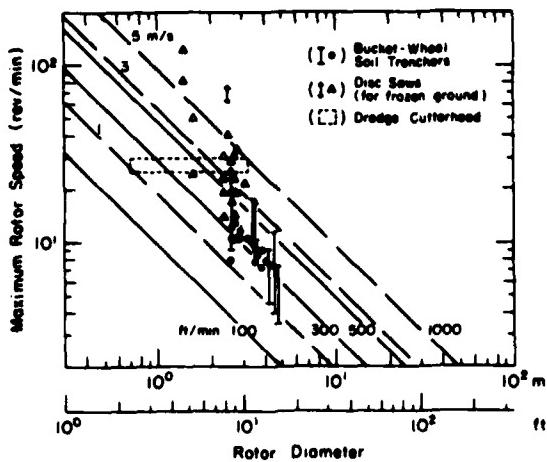
It is not too surprising to find that tool speeds are comparable. A number of kinematic and dynamic factors combine to set practical limits to tool speed, and very high speeds lead to accelerated tool wear.

Figure 2a gives a plot of installed power against gross weight for Soviet machines. The proportionality lines represent various values of power/weight ratio. For most of the machines represented, power/weight ratio is in the range 0.002 to 0.440 hp/lbf (0.003 to 0.007 kW/kgf). There is no definite trend of power/weight ratio with machine size, but the heaviest machines do seem to be the ones with the highest power/weight ratios.

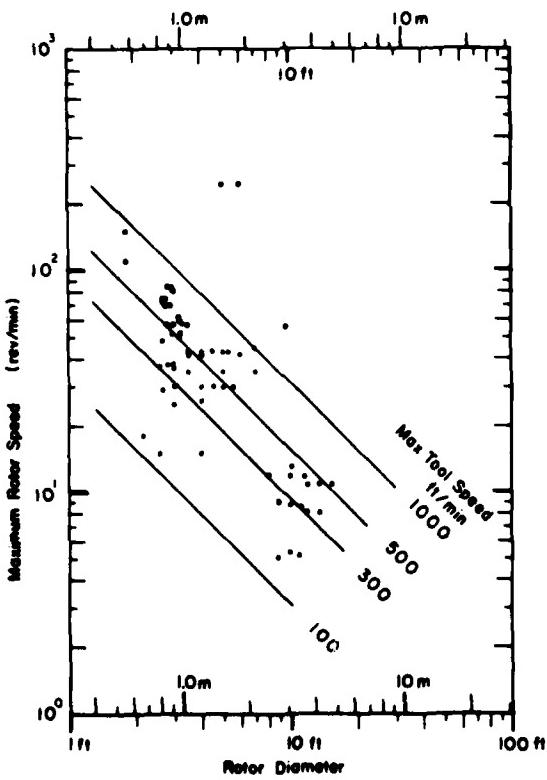
The corresponding data for North American and European machines are given in Figure 2b. Here the range of power/weight ratios is from 0.002 to 0.01 hp/lbf (0.003 to 0.016 kW/kgf) and there is no overall trend with machine size. The general impression is that these machines are more powerful than the Soviet ones represented in Figure 2a. The same impression prevails when the comparison is made solely for wheel trenchers and disc saws, but for the largest of these machines there is not much of a difference.

The lower range of power/weight ratios in Figure 2b covers heavy carriers with relatively low-powered cutting units and also machines that have a lot of auxiliary equipment, such as the gathering arms and conveyors on mining machines. At the upper limit of power/weight ratios in Figure 2b, power may be nearing the limit of what can be utilized before traction of the carrier vehicle sets a performance limit.

Estimates of power density for the cutting rotor are made from Figure 3a, in which the approximate usable rotor power is plotted against the perimeter area for one quadrant of the rotor. The proportionality lines represent fixed values of power per unit area, which is referred to here as power density. Usable rotor power had to be estimated from data for total installed power. For some machines, there was information on the type of transmission (mechanical or hydraulic), and in some cases there were published figures for rotor power. However, because of inconsistencies in the latter, it was finally decided to take "approximate usable rotor power" as 80% of the installed power. For the "nominal working surface

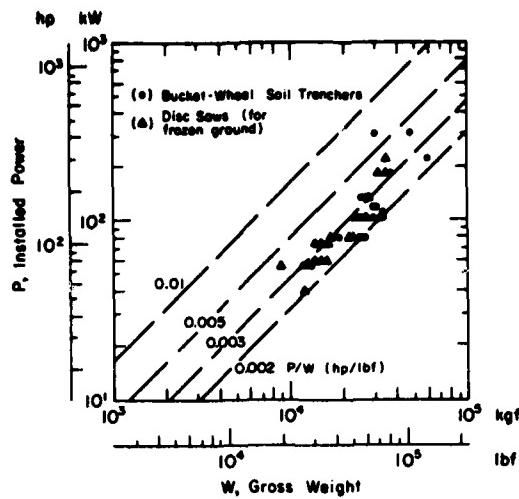


a. Soviet machines.

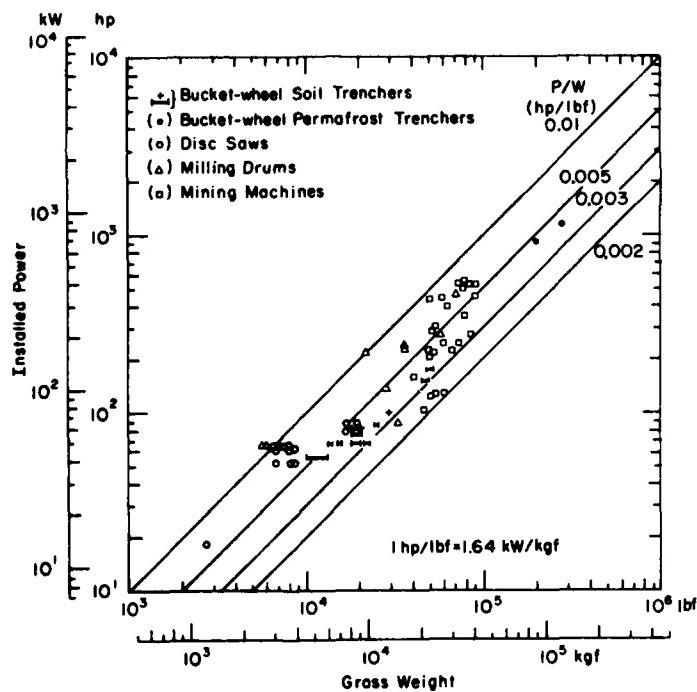


b. North American and European machines.

**Figure 1.** Plots of maximum rotor speed against rotor diameter for (a) Soviet machines and (b) machines built in North America and Europe (including transverse rotation machines for mining and tunneling).



a. Soviet transverse rotation machines.



b. North American and European machines.

**Figure 2.** Plot of installed power against gross weight for transverse rotation machines built in (a) the USSR and in (b) North America and Europe (including mining and tunneling machines).

"area" of the rotor, one-quarter of the rotor circumference was multiplied by the cutting width, even though some rotors cut to a maximum depth of less than one radius, while others cut to a maximum depth that is greater than one radius.

Most of the Soviet disc saws and trenchers appear to have nominal power densities in the range 2 to 7 hp/ft<sup>2</sup> (16 to 56 kW/m<sup>2</sup>), but some trenchers show appreciably higher values, up to about 28 hp/ft<sup>2</sup> (225 kW/m<sup>2</sup>).

Corresponding data for Western machines are given in Figure 3b. Large wheel trenchers ave power densities quite similar to those of their Russian counterparts; the range is from about 3 to 10 hp/ft<sup>2</sup> (24 to 80 kW/m<sup>2</sup>). However, US disc saws intended primarily for cutting concrete and rock have higher power densities, up to about 30 hp/ft<sup>2</sup> (240 kW/m<sup>2</sup>).

#### Continuous Belt Machines

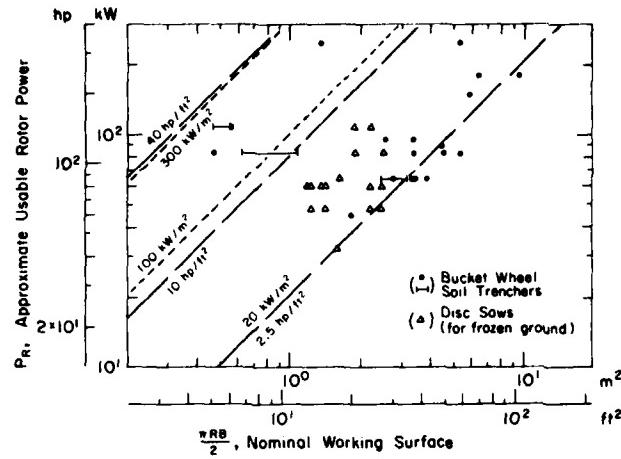
The term "continuous belt" is used here to describe machines such as chain saws, ladder trenchers, and bucket chain trenchers.

Figure 4a is based on a plot of rated belt speed against available traverse speeds for Soviet machines. Because of the large number of data points and spread bars (for continuously variable transmissions), the original plot became confusing and only the data envelope for chain saws is shown in this figure.

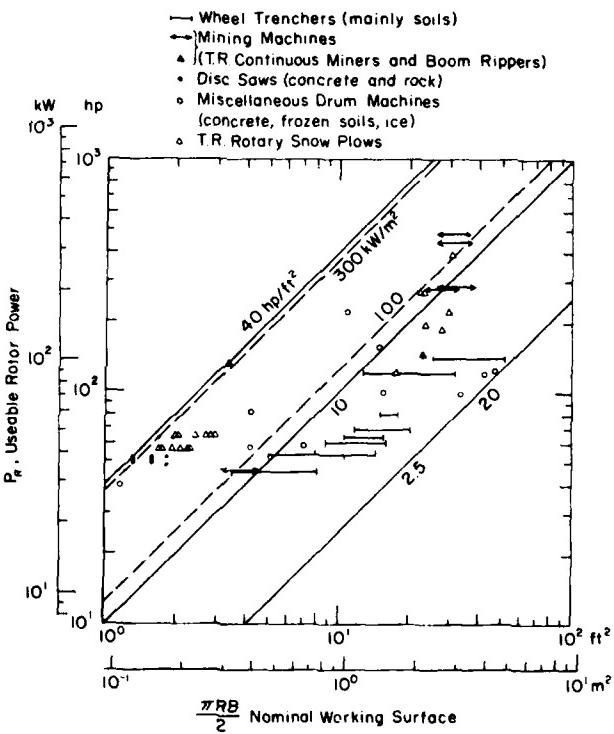
The belt speeds, or tool speeds, of the Soviet chain saws range from 150 to 750 ft/min (0.76 to 3.8 m/s). This speed range is quite similar to the range of tool speeds for the Soviet transverse rotation machines. The traverse speeds of carrier vehicles range from about 0.15 to 25 ft/min, or 3 to 500 m/hr.

The proportionality lines in this plot give fixed values for the ratio of belt speed to traverse speed, although the labels give the inverse of this value. The significance of this ratio is that it gives a measure of the angle of penetration of the cutting teeth. The potential range for the Soviet machines is from about  $10^{-1}$  to less than  $10^{-3}$ .

Data for North American and European machines are covered by the envelopes in Figure 4b. With the exception of rock cutting quarry saws, the characteristics of these machines are quite similar to those of their Russian counterparts. However, the data for coal cutters, a permafrost saw, and an ice saw give better definition of the requirements for working hard ground and provide some idea of realistic combinations of operating parameters. These include traverse speeds in the range 1 to 10 ft/min (18 to 180 m/hr), tool speeds in the range 400 to 800 ft/min (2 to 4 m/s), and speed ratios in the range  $2 \times 10^{-3}$  to  $2 \times 10^{-2}$ . It might be mentioned that high values are desirable for the ratio of traverse speed to tool speed, but there are practical limits set by forces and torques in the drive train and by forces on the cutting tools.

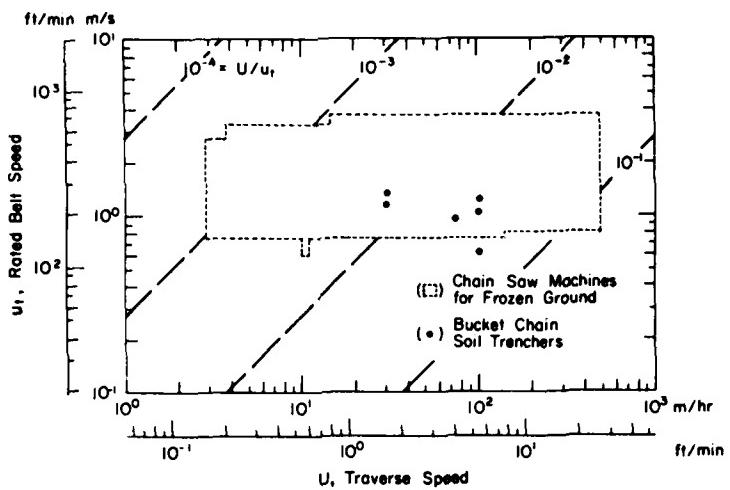


#### a. Soviet machines.

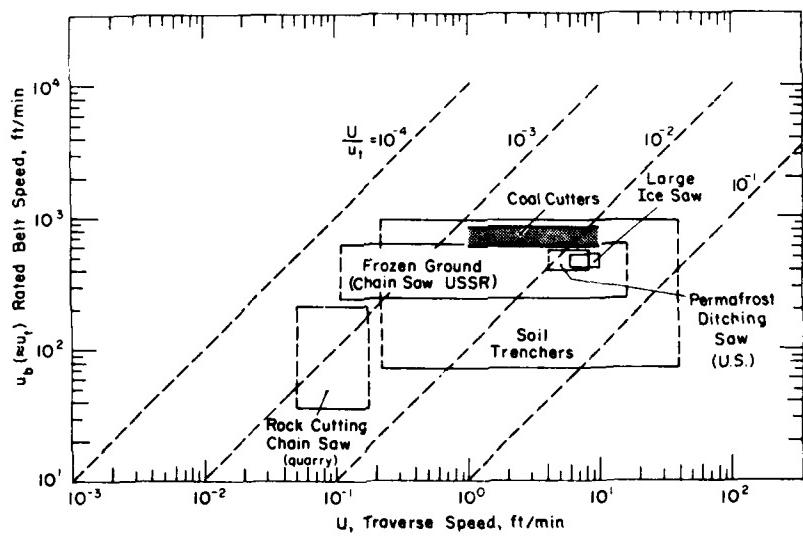


#### b. North American and European machines.

**Figure 3.** Plot of approximate usable rotor power against nominal working surface for (a) Soviet and (b) North American and European machines.



a. Soviet machines.



b. North American and European machines.

Figure 4. Plot of rated belt speed against traverse speed for (a) Soviet and (b) North American and European machines.

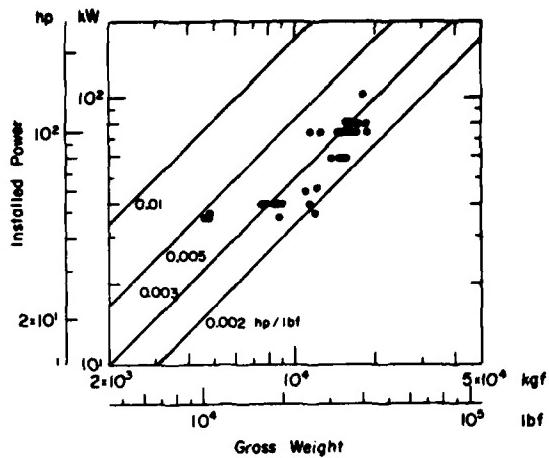
Figure 5a gives information on power/weight ratios for chain saw machines designed to cut frozen ground in the USSR. The range is from 0.002 to 0.005 hp/lbf (0.003 to 0.008 kW/kgf). There is no clear trend of power/weight ratio with machine size, although the highest values are given by the smallest machines (the opposite of the situation for transverse rotation machines).

Information on power/weight ratio for US machines is provided in Figure 5b. Most of the ladder trenchers and coal cutters have power/weight ratios in the range 0.005 to 0.01 hp/lbf (0.008 to 0.016 kW/kgf). Only the large bucket-chain soil trenchers and some coal cutters are in a lower power/weight range (0.003 to 0.005 hp/lbf, or 0.005 to 0.008 kW/kgf). There is no trend with machine size. Power/weight ratios for these belt machines are quite similar to those for transverse rotation machines (Fig. 2b).

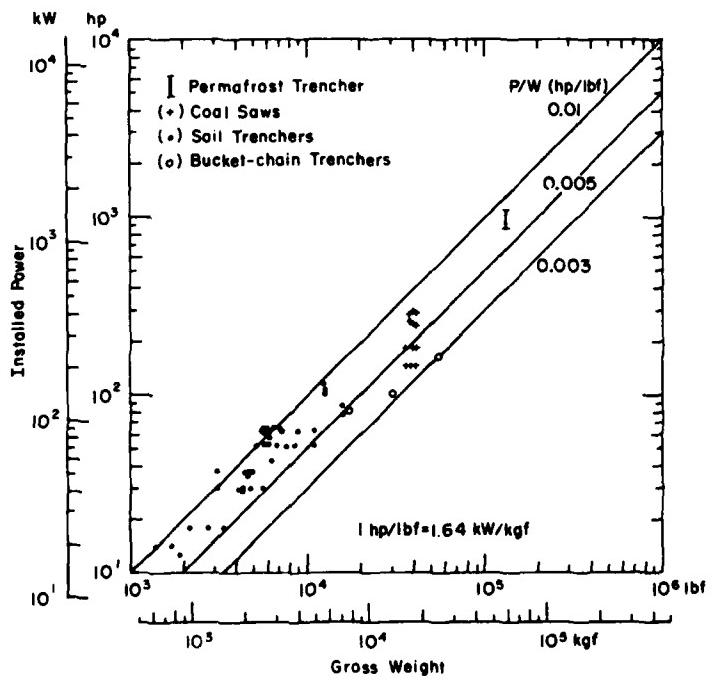
In Figure 6a the estimated cutting power for Soviet belt machines is plotted against the maximum rated cutting area. As was the case for transverse rotation machines, cutting power was estimated as 80% of the installed power, since there were inconsistencies and improbable values in reported figures. The rated cutting cross section is given by the product of trench width  $B$ , maximum trench depth  $d$ , and number of parallel tranches  $n$  (since some Soviet machines have two or three cutter bars). Maximum trench depth is usually achieved with the cutter bar close to vertical, so that cutting power divided by rated cutting cross section gives a measure of power density. The overall range of power density for these machines is 5 to 35 hp/ft<sup>2</sup> (40 to 280 kW/m<sup>2</sup>). Much of the variation may be the result of fitting different cutting units to a limited range of carrier vehicles, which have engines ranging from about 50 to 100 hp.

Figure 6b gives the corresponding data for Western machines. The large bucket-chain soil trenchers have very low power densities, about 1 to 4 hp/ft<sup>2</sup> (8 to 30 kW/m<sup>2</sup>). Typical ladder trenchers designed for work in unfrozen soils have power densities in the range 5 to 20 hp/ft<sup>2</sup> (40 to 160 kW/m<sup>2</sup>). Coal cutters (plus the single machine designed for work in permafrost) have power densities in the range 20 to 50 hp/ft<sup>2</sup> (160 to 400 kW/m<sup>2</sup>). The upper limit of the latter range is probably close to the practical attainable limit with current technology. Cutting teeth could probably not transmit power at higher densities without excessive wear and breakage, and there are limits to the size of the power plant that can be carried on mobile machines that have to cut a large face area.

The final data plot for Soviet machines (Fig. 7a) relates power density to belt speed. The proportionality lines give a measure of "nominal belt pressure," a parameter that is explained in Part VIII of Mechanics of Cutting and Boring. Figure 7a shows little correlation between power density and belt speeds, and it indicates a range of nominal belt pressures from 2 to 50 lbf/in<sup>2</sup> (14 to 350 kN/m<sup>2</sup>).

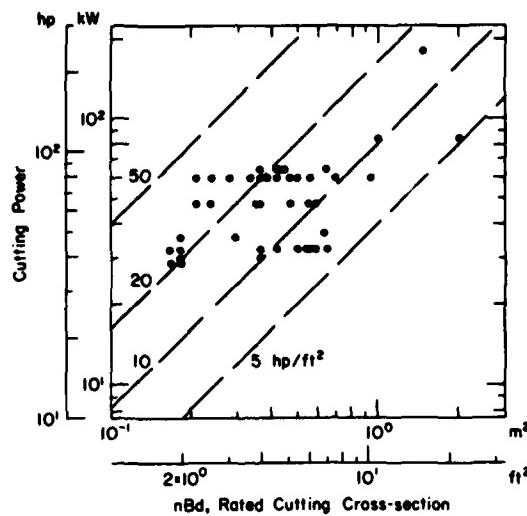


a. Soviet belt machines.

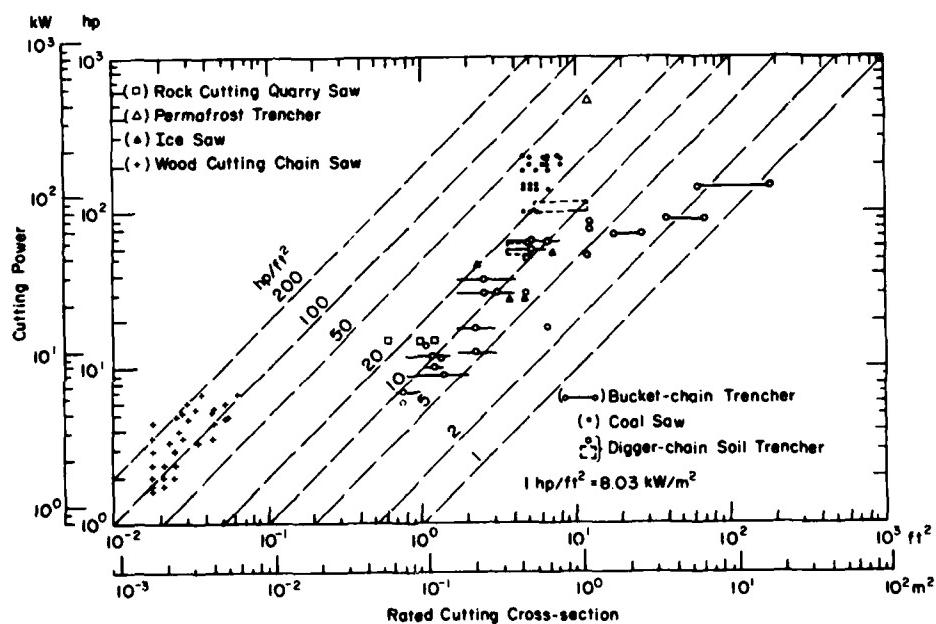


b. US belt machines.

Figure 5. Plot of installed power against gross weight for (a) Soviet belt machines and (b) US belt machines.



a. Soviet machines.



b. Western machines.

Figure 6. Plot of estimated cutting power against rated cutting cross section for (a) Soviet and (b) Western machines.

The corresponding data for a broad range of Western machines (Fig. 7b) show nominal belt pressures of comparable magnitude, but it is possible to discern some trends. Large bucket-chain trenchers for soft soils have low nominal belt pressures, while quarry saws for cutting hard rock have very high nominal pressures. If a machine is to be successful in cutting frozen soils, the nominal belt pressure probably has to be about 10 to 20 lbf/in<sup>2</sup> (70 to 140 kN/m<sup>2</sup>) or higher.

#### General Comments

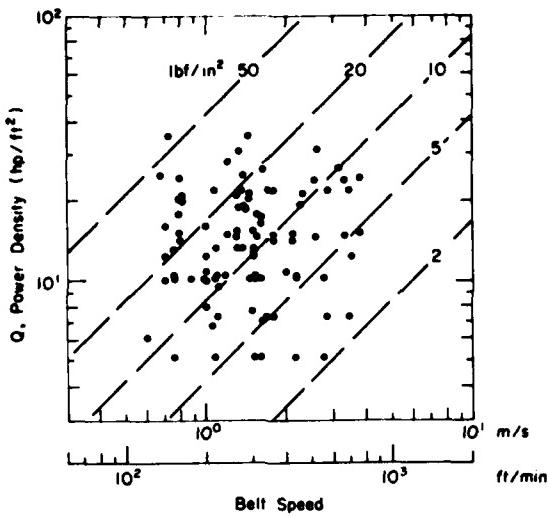
During the course of a seven-week trip, many construction sites were visited in Leningrad, Novosibirsk, Bratsk, Yakutsk, and Neriungri. There were no frozen ground excavating machines of the bar or disc types in use or on standby at any of these sites. A disassembled bar machine\* in a workshop and a disabled bar machine by the roadside were seen at Bratsk. In Leningrad, a bar machine was seen parked on a street. Another bar machine was glimpsed while driving past a building site en route to the Novosibirsk airport. This tends to strengthen the feeling that many of the machines described in Soviet technical journals may have been built in rather small numbers, or in some cases may not have gone into production at all.

The Soviet technical literature creates the impression that bar machines and disc machines provide a well-developed capability for cutting trenches and slots in frozen ground of all types. This is probably a false impression. The bar machines seem to be equipped with coal-cutter chains and with the light-duty carbide-tipped teeth typically used in coal mining. The few machines that were seen all showed severe wear and damage to the chain, the bit holders, and the bits themselves. On the basis of considerable prior experience, the writer believes that the typical Soviet bar machines would have very little chance of cutting frozen gravel or frozen till.

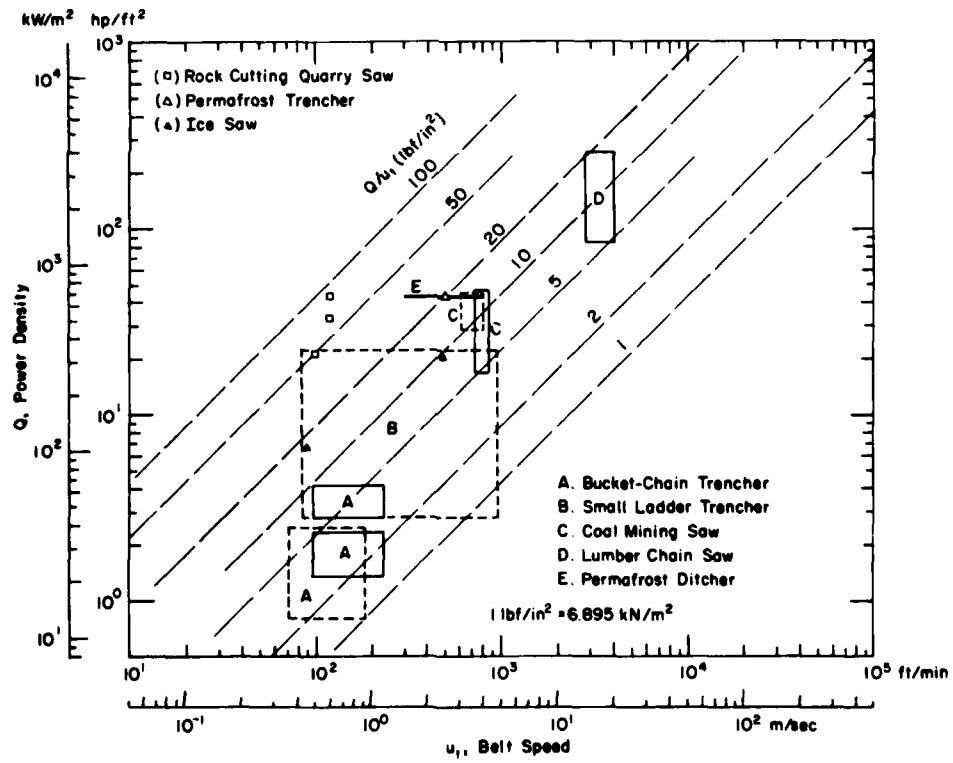
Studies in the library at Novosibirsk indicate that a number of Soviet research groups engaged in the design of excavating machines are highly competent, and have a sophisticated understanding of the relevant principles and material properties. This being so, the basic design characteristics of Soviet machines are likely to be sound. However, some sectors of Soviet industry seem weak on product development prior to quantity production, and there is probably little refinement of products as a result of user experience and subsequent feedback. Whatever the reasons, the few examples of bar cutters seen by this writer were unimpressive in appearance.

Engineers and planners in the Soviet Union obviously perceive a significant need for cutting trenches in frozen soils, and they clearly are encouraged to believe that bar and disc machines have the capability for doing the work. By contrast, there has not been a great deal of trenching in frozen soils in North America, and proposals to do such work with bar and disc machines have not generated much enthusiasm, mainly because of tooth replacement costs. This difference of opinion probably derives from different economic imperatives in the two countries.

\*Soviet term for a belt machine with a rigid support bar.



a. Soviet machines.



b. Western machines.

**Figure 7.** Plot of power density against belt speed for a variety of (a) Soviet and (b) Western machines.

It seems quite possible that a well-built trench cutter attachment for construction tractors would find ready acceptance in North America. However, if such a thing does appear, it is likely to have been made in Japan.

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